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THE

ARTIFICIAL EYE

OF

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TRANSLATED

BY

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PREFACE.

THE "Artificial Eye" is one among the many of Dr. Landolt's contributions towards our means of accurately measuring the eye-ball. The experiments described in the following pages are exceedingly simple, but do, in fact, constitute a course of instruction in refraction and accommodation of great utility to the student. I need scarcely remark on the superiority of knowledge acquired by experiment over that acquired by mere reading. By means of the artificial eye the student may learn all the important facts by actual observation, and may compare the results thus empirically obtained with those required by calculation.

The model in my possession was made for me by M. Crêtes, optician, 66 Rue de Rennes, Paris. The results of experiments accord with the statements in the text within very narrow limits.

Dr. Landolt has kindly corrected the proofs of the translation.

E. A. B.

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OF

DR. LANDOLT,

DIRECTOR OF THE OPHTHALMOLOGICAL LABORATORY AT THE SORBONNE, PARIS.

It is well known that in 1851 M. Listing substituted a *reduced* or *simplified* eye for his *schematic* eye to facilitate observations on physiological optics.

The simplified eye of Listing is the same length as the real eye, but for the complicated dioptric system of the latter he substituted a single spherical surface, which separates the air from the interior of the eye. This is filled with a liquid having an index of refraction equal to that of the aqueous or vitreous humours. By this arrangement calculations in physiological optics have been considerably simplified.

Donders rendered the calculations still simpler by stating the dimensions of Listing's simplified eye in round numbers, and especially by substituting a radius of curvature of 5 mm., in place of 5.1248 mm., and in taking $\frac{4}{3}$ as the index of refraction instead of $\frac{103}{77}$.

In the construction of our artificial eye we have taken Donders' reduced eye as our standard.

Our artificial eye consists essentially of a spherical cornea, excessively thin, with parallel surfaces, and a radius of curvature of 5 mm. It is filled with water, of which the index of refraction is $\frac{4}{3}$.

The retina is represented by a ground glass, on which the retinal images are formed almost identically of the same dimensions as those on the retina of the living eye.[1]

[1] According to the researches of Hirschberg, it is merely necessary to multiply the dimensions of the retinal images in the reduced eye by 1.1 to obtain the exact dimensions of the retinal images in the real eye.

The size of the images can be directly estimated by the aid of a small glass disc, ruled with parallel lines half a millimetre apart. This graduated glass is applied directly to the ground surface of the artificial retina. It is mounted in a cylindrical tube, and furnished with a lens capable of a to-and-fro movement, for the purpose of focussing the graduated plate.

Of course, the observer must adapt the lens to his own sight before making use of it. The lens is at the required distance for each observer when he sees the lines of the division quite distinctly.

In the condition of *emmetropia,* the eye is 20 mm. long, from the summit of the cornea to the retina. In this case the external surface of the retina corresponds with the point 0 or zero, marked on a small horizontal scale fixed behind the eye.

By turning the screw, the eye can be shortened (bringing the retina nearer to the cornea than zero), and thus is constituted an *axial hypermetropia,* higher in degree in proportion as the retina approximates to the cornea.

On the other hand, by turning the screw in the opposite direction, and increasing the distance between cornea and retina beyond zero, the eye can be lengthened, and thus is constituted an *axial myopia.*

Our artificial eye, by the aid of this mechanism, can be shortened or lengthened 3 mm., equivalent to a hypermetropia or myopia of 10 dioptrics (about $\frac{1}{4}$ old measurement).

All the degrees of ametropia between emmetropia and a hypermetropia, or a myopia of 10 dioptrics, can therefore be produced, and the scale indicates the difference in length that exists between an emmetropic eye and an ametropic eye of the given degree.

In front of the eye is arranged a horizontal stem, graduated in millimetres, starting from the nodal point of the eye. The nodal point of the reduced eye coincides with the centre of curvature of the cornea, and is then situated 5 mm. behind its anterior surface. The stem carries two frames for the reception of correcting lenses, test-types, ground glass screens, diaphragms, with stenopœic slits, &c.

Accommodation is effected in our artificial eye, in the same

manner as in the living organ, by increasing the curvature of the refracting surface. For this purpose we apply to the cornea a meniscus, having for its anterior surface a radius of curvature of 4.4 mm., and which, in supplanting the surface of 5 mm. curvature, adapts (*i.e.*, is equivalent to an effort of accommodation) the emmetropic eye for a point situated 120 mm. in front of its nodal point.

A small drawing, which can be applied to the retina, or the V engraved in the division of the fundus, serves as an object for ophthalmoscopic examination.

Our artificial eye enables us to ascertain by actual observation the effect of differences in the length of the eyeball upon its refraction; upon the clearness and size of the retinal images both of near and remote objects, for which the eye can be adapted, either by its state of refraction, or by accommodation, or by correcting lenses placed at different distances, by optical instruments and by stenopœic slits. It can thus be used to study the effects of these various modes of adaptation, especially the influence of spectacle lenses upon the acuteness of vision.

It is also useful in ophthalmoscopy, for the determination of the refraction, for the study of the ophthalmoscopic images, and the measurement of the dimensions both of the inverted and erect images.

Besides this, the eye will serve for many experiments, especially for the verification of different optometers and optometrical methods. For instance, let us illustrate the capabilities of the artificial eye by a few experiments.

Let us first render it *emmetropic*. (The retina stands at the point o.) The eye should now see clearly at a distance. As a matter of fact, distinct inverted images of distant objects are formed on the artificial retina. Place the eye opposite the test-types at a distance of 5 metres, as in the practical determination of visual acuity, and with the aid of the lens we can perfectly distinguish the characters on the retina.

Let us now take an object 50 centimetres long. For instance, draw across the test-card a black band 50 centimetres from the upper border of the card, and we shall see that the image of this part of the card covers 3 spaces of the scale marked on the

retina. This retinal image, therefore, has a diameter of 1.5 mm. since each division = 0.5 mm.[1]

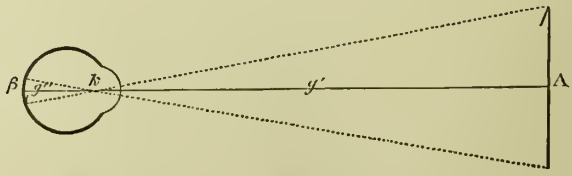
Our artificial eye, then, can see clearly at a distance, but cannot see near objects. Let us place some small object, some printed lines, for instance, in one of the frames on the stem, and adjust it at the point 120 on the scale, in a good illumination. The retinal image of that object will be blurred. To see at this short distance, the eye must either exercise its accommodation, or be furnished with convex glasses, or a stenopœic hole, or it must be so myopic that its *punctum remotum* coincides with the distance of the object.

To effect *accommodation* we have the meniscus, which adapts the eye for the distance of 120 mm. As a matter of fact, the augmentation of curvature suffices to render the retinal image perfectly clear. If we choose an object of 15.3 mm. in diameter, its image will be 2 mm.

Remove the meniscus and adapt the eye by means of a convex lens. What is the positive lens that will adapt an emmetropic eye for a distance of 120 mm. in front of its nodal point? That depends upon where the lens is placed. Obviously, as the emmetropic eye is adapted for infinite distance (parallel rays), it is necessary that the auxiliary glass must give a parallel direction to the divergent rays proceeding from the near object. For that purpose, the object must be situated at the principal focus of the lens. Then the nearer the convex lens is placed to the object, the shorter will be its focus and the greater its refracting power.

[1] In the subjoined figure let A be the object; β the retinal image; k the nodal point; $kA = g'$ the distance from the nodal point to the object; $k\beta = g''$ the distance of the nodal point from the retina.

We then have: $\frac{\beta}{g''} = \frac{A}{g'}$. Then $\beta = \frac{g'' \times A}{g'}$.



So that with $A = 500$ mm.; $g' = 5000$ mm.; $g'' = 20 - 5$ mm. $= 15$ mm., we should have $\beta = \frac{15 \times 500}{5000} = 1.5$ mm. as shown by experiment.

Place the lens at 5 centimetres from the object (at $120 - 50 = 70$ mm. from the point 0 on the scale). This is the number 20 D (2 inches English). This lens, under the above-named conditions, will give a defined retinal image which will be larger than the image obtained by accommodation. The object of 15 mm. will form an object of more than 4 mm. in diameter.

Place the lens at 20 mm. in front of the nodal point,[1] and it will have $120 - 20 = 100$ mm. focal length. That is 10 D (4 inches). The eye is again adapted for that distance, but the retinal image of an object will only be 2.3 mm. in diameter.[2]

[1] The point situated at 20 mm. in front of the nodal point, or 15 mm. in front of the cornea, has a special optical significance. It is the *anterior focus* of the eye, and in the living eye is placed at about 13 mm. in front of the cornea.

[2] Spectacle glasses are habitually placed at this distance in testing the degrees of ametropia. In our example we should say "the eye is myopic 10 D." Our artificial eye also serves to determine the influence of lengthening (or shortening) of the axis of the eyeball on the degree of ametropia. Donders has already given a formula for calculating the difference η between the length of the emmetropic eye and that of the ametropic eye. This formula is—

$$\eta = \frac{300}{F}$$

where 300 is a constant number of mm.; F, the focal length of the correcting lens, placed at the anterior focus of the ametropic eye. In our example $F = 100$ mm. We have then—

$$\eta = \frac{300}{100} = 3 \text{ mm.}$$

We have lengthened the artificial eye 3 mm. to produce a myopia of 10 D. By shortening it 3 mm., we shall produce a hypermetropia corrected by a lens + 10 D placed at the anterior focus. This is a suitable occasion for adapting the formula of Donders to the new nomenclature. Let us call d the number of dioptrics of an ametropia, η, as before, the number of millimetres that an ametropic eye is longer or shorter than an emmetropic eye, and we obtain—

$$\eta = \frac{3\,d}{10} \text{ or } d = \frac{10\,\eta}{3}$$

In our example $d = 10$ D, then—

$$\eta = \frac{3 \times 10}{10} = 3 \text{ mm.}$$

Let $d = 1$, η becomes 0.3 mm. That is to say, for a lengthening of the eyeball of 0.3 mm. the ametropia increases 1 D; for an equal amount of shortening it diminishes 1 D.

Or if we have an ametropia of a certain degree, we have only to multiply by 0.3 the number of dioptrics it contains in order to obtain the corresponding amount of lengthening or shortening of the eyeball.

We can easily verify the truth of this rule by the aid of the artificial eye. If we lengthen or shorten it 1 mm., we obtain a myopia or hypermetropia corrected by 3.3 D placed at 20 on the scale; for 2 mm. an ametropia corrected by 6.6 D, &c.

Lastly, let us take a glass which we apply immediately to the cornea itself. It will require to be $120 - 5 = 115$ mm. focal length. This is 8.69 D, nearly $4\frac{1}{2}$ old style (say $4\frac{3}{4}''$ English). Take number 9 D, the image will be defined, and will be 2.2 mm. in diameter, as in the case of the eye adapted by accommodation.

Now let us make the eye *myopic*, so that its far point shall be at 120 mm. from its nodal point. In lengthening the eye we shall find that, in conformity with our formula, that will be when the retina is 3 mm. beyond zero. The retinal image will be defined, and will be 2.3 mm. in diameter.

Our experiments have determined several important facts:—

1. The retinal image formed by the eye exercising its accommodation is always smaller than that formed by the aid of a convex lens, the accommodation being relaxed, except when the convex lens is actually in contact with the eye.

2. The farther the convex lens is removed from the eye, the larger is the retinal image.

3. A myopic eye, viewing objects placed at its far point, will have larger retinal images than an emmetropic eye, by the exercise of its accommodation. The size of these images will be the same as those formed in an emmetropic eye looking through a convex lens placed at its anterior focus.

An emmetrope, then, who wishes to render his vision the same as it would be with an axial myopia of 6 D, has only to place the test-types at 18 centimetres (the distance of the far point in this degree of myopia), and to view them through a convex lens 6 D placed at 13 mm. in front of his cornea. The types will appear much larger than without the glass. This is the explanation of why a myope who at a distance has an acuity of vision below normal, even when aided by correcting glasses, is often able to make out smaller details close at hand that an emmetrope endowed with a normal, or even more than normal, acuity of vision cannot see.

4. It is noticeable that the axial myope is placed in a more favourable condition than the myope from curvature, inasmuch as he receives larger retinal images. In fact, an emmetropic eye, under accommodation, can be regarded as an eye rendered myopic by an excess of curvature in one of its refracting sur-

faces, as it is adapted for a short distance without any change in the length of its axis.

Thus lengthened, the eye has become *axially myopic.* Remove the object beyond the far point, and we shall see that the images of distant objects are no longer distinct. We have, therefore, to correct the myopia by means of concave glasses in order to make the eye see clearly at a distance.

What number shall we give our myope? That evidently depends upon the distance at which we place the correcting glass. In a state of rest the eye is adapted for its far point, which in the example given is 120 mm. in front of its nodal point. To enable a myopic eye to see at a distance, the correcting glass must give to parallel rays impinging on it the same degree of divergence as they would have if they emanated from the far point of this eye. To realise these conditions, the lens must be concave, and its focus must coincide with the far point of the myopic eye.

If we apply the concave lens immediately to the cornea, it must be of 115 mm. focal length, very nearly -9 D. In this case the images of distant objects will be extremely clear; and if we again employ our test-object of 50 centimetres diameter, placed at 5 metres, we shall find the image occupying more than three divisions on the retina—that is to say, more than 1.5 mm. in diameter.

Now place the concave lens at 20 mm. in front of the nodal point. For its focus to correspond with the far point of the myopic eye it must be $120 - 20 = 100$ mm. in focal length, or 10 D (nearly 4″). The ametropia will be corrected, and the image will be exactly 1.5 mm. in diameter.

It is practically at this distance that we place spectacle lenses, and, following the commonly adopted expression, we have before us "a myopia of 10 D."[1]

Lastly, take a concave lens of 50 mm. focal length, number 20 D (about 2″); place it at 50 mm. from the far point, and, of course, at 70 mm. from the nodal point, and the retinal image will still be clear, but much smaller than in the former experiments.

[1] This again confirms the formula for η.

From these last experiments we deduce the following important conclusions:—

1. The same myopia can be corrected by different concave glasses, but these glasses require to be stronger in proportion as they are removed from the eye.

2. The retinal images are smaller, and the visual acuteness consequently diminished, in proportion as the glass is distant from the eye, or, what comes to the same thing, the greater its strength.

3. When the correcting glass is placed between the anterior focus of the eye and the cornea, the retinal images in axial myopia are larger than those in emmetropia. When the correcting glass is placed at the anterior focus, where spectacles are habitually placed, the retinal images of the axial myope are exactly the same size as those of the emmetrope. Under these conditions the visual acuity of the myope, no matter what correcting glass he requires, is exactly comparable with that of an emmetrope, as the diminishing effect of the concave glass is compensated for by the enlarging influence of the lengthened eyeball.

4. But if the myope selects a stronger concave glass placed beyond the anterior focus of the eye, the retinal image will be smaller than in emmetropia.

To study the effect of correcting glasses on the visual acuity (or the size of the retinal images) in the *myopia of curvature*, we must render the eye emmetropic in length, and apply the meniscus to the cornea. Let the degree of myopia be the same as we have already investigated.

In repeating the experiments with correcting glasses placed at various distances, we shall find that it is only when the concave lens is placed immediately on the cornea that the retinal images are equal to those in emmetropia. This may be easily understood: An emmetrope can see clearly at a distance through a concave glass, but he sees things smaller than without the glass. By means of his accommodation he converts his emmetropia into a myopia of curvature, which he corrects by the concave glass.

By shortening the eye we produce *axial hypermetropia*, and

we perceive the retinal images become more and more indistinct in proportion as the retina is moved from the point zero. The shorter the eyeball the more hypermetropic.

Shorten the eyeball 3 mm., and determine the degree of hypermetropia thus produced, as we do practically by means of convex glasses placed at 20 mm. in front of the nodal point; we shall find that 10 D will give the clearest retinal images. According to practical nomenclature, the eye will be hypermetropic 10 D.[1]

What would be the action of this convex lens on parallel rays, emanating from infinite distance, if the eye were not there to disturb the direction after they had passed through the lens? The lens would reunite them at its focus 100 mm. behind it. This can easily be proved. If the object is sufficiently luminous, we have only to place at 100 mm. from the lens a white screen, on which we shall see the image of the distant object, formed by the reunion into foci of the parallel rays which emanate from it.

The luminous rays then converge, on leaving the lens, towards a point situated at 100 mm. behind it; and if the hypermetropic eye is placed behind the lens so that the cornea is 15 mm. from it, the luminous rays will be united on the retina. This proves that this hypermetropic eye, in order to see clearly, requires rays converging to a point situated $100 - 15 = 85$ mm. behind its cornea. That is the far point (negative) of the hypermetropic eye.

We therefore find the conditions identical with those of myopia: *The focus of the correcting glass must coincide with the far point of the ametropic eye;* so that if we place a correcting glass immediately upon the cornea, in order to bring parallel rays to a focus at the eye's far point, 85 mm. behind the cornea, it must be a glass of 85 mm. focal length, or 12 D (about $3\frac{1}{2}''$). This glass gives clear retinal images, and is the proper lens for the correction of the hypermetropia.

Now, let us choose a weaker glass, for instance, number 8 D (about $5''$), which is 125 mm. in focal length; where must it be placed in order to correct the hypermetropia of the eye? At

[1] This again results from the formula for $\dot{\eta}$.

125 mm. in front of the far point, which is 80 mm. behind the nodal point (zero), or, in other words, at $125 - 80 = 45$ on the scale.

It is then possible to correct hypermetropia by means of different lenses; by stronger lenses placed closer to the eye, by weaker lenses placed farther off. The retinal images will be equally clear, but they will not be of the same size; so that if we take the same test-object as before and place it at the same distance we shall find—

1. That the retinal image is smaller than in emmetropia when the convex lens is placed between the cornea and the anterior focus of the hypermetropic eye.

2. By placing the correcting glass at the anterior focus, at 20 on the scale, we obtain an image of exactly the same size as in emmetropia or in axial myopia corrected under similar conditions.

3. Lastly, the farther we place the correcting glass beyond the anterior focus—that is to say, the weaker the lens—the more the images are increased beyond the dimensions of those in emmetropia.

Finally, let us apply the correcting lens immediately to the cornea; it must be 85 mm. in focal length, equivalent to 12 D. The correction is still perfect, but the retinal image is smaller than before, although the lens is stronger.

The convex lens applied to the artificial eye is evidently equivalent in effect to an increase in curvature, that is, to an effort of accommodation. Our meniscus of 4.4 mm. radius of curvature will supply the accommodation correction for a hypermetropia of 8 D ($\eta = 2.4$ mm.). The eye made hypermetropic to 8.3 D, furnished with the meniscus, forms retinal images which are exactly the same size as those formed by applying a lens 8.30 directly on the cornea. These retinal images are always smaller than those of the emmetropic eye. In fact, a hypermetropic eye accommodated is, so to speak, an emmetropic eye abnormally short. We have, then, established these important facts—

1. The hypermetropic eye can be corrected by different convex lenses, but these lenses must be weaker in proportion as they are farther from the eye.

2. The correcting convex lenses increase the retinal images in proportion to the distance they are placed from the eye, that is to say, the weaker they are.

3. The retinal images of an axial hypermetropic eye are smaller than those of an emmetropic eye, so long as the hypermetrope effects the correction by the aid of his accommodation, or by means of a lens placed between the cornea and the anterior focus of the eye.

4. When the correcting lens is placed at the anterior focus (where spectacles are usually placed), the retinal images of the compensated hypermetrope are the same size as in emmetropia or in axial myopia similarly corrected.

5. The farther the lens is carried beyond the anterior focus, the more the retinal images of the hypermetrope surpass those of the emmetrope in size.

To see near at hand the hypermetrope requires stronger glasses than the emmetrope in proportion to the degree of the defect. For example, place the correcting lens at the point 20 in front of the hypermetropic eye, and place the second frame carrying the test-type at the point 120; the image will be blurred, and will only be rendered clear by the addition to the correcting lens 10 D of a second lens of 10 D. The hypermetrope of 10 D, then, requires a glass of 20 D to see at 10 centimetres, 10 D render him emmetropic, and 10 D to accommodate from infinite distance to 10 centimetres (about 4″ English).

It is interesting to note that when the convex lens is placed at the anterior focus, the axial hypermetropic eye obtains retinal images as large as an emmetropic eye similarly corrected, or to those of a myopic eye of which the far point corresponds with the distance of the test-type. In choosing a weaker glass, but placed nearer, or in accommodating wholly or in part, the hypermetrope will see objects smaller; by placing a stronger glass at a greater distance he will obtain larger retinal images.

A meniscus with a radius of curvature for the external surface of more than 5 mm., or a concave glass applied directly to the cornea of the artificial eye (arranged as emmetropic), will give rise to *hypermetropia by curvature.* In this way the eye can be rendered comparable to an eye operated upon for cataract

(aphakia). In repeating the experiments on the influence of correcting glasses on the size of the retinal images, we have established that, other things being equal, the retinal images of an eye hypermetropic by curvature are always larger than the images in an axial hypermetropic eye, and even larger than those of an emmetropic eye, unless the correcting glass touches the cornea.

If we furnish one of the movable frames with a diaphragm pierced with a stenopœic opening, and place it as close as possible to the cornea, we shall find that the eye can form, both of distant and near objects, fairly distinct images without being otherwise corrected. But these images are always badly illuminated.

By adapting a cylindrical glass to the cornea of the artificial eye *astigmatism* is produced, and we can study the irregularities of the retinal images resulting from that anomaly of refraction.

To verify optometres, place the artificial eye behind the eyepiece of the instrument in the same place that would be occupied by the eye of the patient. By arranging the eye for various degrees of refraction and adapting the optometre to the same degree, it is easy to measure the size of the retinal images that would in practice be produced by the optometre in such eyes. It is obvious that when these images are of different sizes, the optometre is not adapted for the determination of the acuteness of vision.

OPHTHALMOSCOPY.

In observing the retinal images we have been concerned with the direction taken by the incident rays of light in the eye. Let us reverse matters. Let us consider the image as the object, and the object as the image, and we shall find the same direction is taken by the emergent rays, as we may determine by the ophthalmoscope.

We shall see, in fact, that the ophthalmoscopic image can be considered as the object of the retinal image, so that if an object of 30 mm. forms an inverted retinal image of 1 mm., a retinal object of 1 mm. forms in the same place an inverted

image of 30 mm. We can also demonstrate that in the same manner as rays coming from infinite distance (parallel) are converged on to a point on the retina to form a clear image, so an object situated on the retina emits luminous rays which are rendered parallel as they quit the eye and pass outwards in the direction of infinite distance.

This follows from the *law of conjugate foci*, in accordance with which the luminous rays, emitted by an object and travelling towards the image, follow the same direction as those which come back from the image; so that with the same dioptric system the image may be substituted for the object or the object for the image indifferently. For this purpose we may make use of a painted *fundus oculi*, which can be fitted behind the ground glass which represents the retina in the artificial eye. Or a still simpler and more demonstrative plan is to apply the before-mentioned graduated disc which is marked with a small V of 1 mm. width.

We commence with the consideration of *emmetropia*.

The emmetropic eye brings parallel rays to a focus on the retina; therefore rays which emanate from the retina of an emmetropic eye are parallel as they pass out from the corneal surface, so that an eye which sees clearly at a distance sees equally clearly the objects on the fundus of an emmetropic eye by means of the ophthalmoscope. The objects appear enlarged and erect, like all objects placed at the focus of a lens. In the case of the eye the lens is represented by the dioptric system and the object by the retina.

Let us now place before the eye a convex lens, for instance, 10 D (100 mm. focal length—about 4″ English), at the mark 20 on the scale. This lens adapts the emmetropic eye for a point situated 100 mm. in front of it; that is to say, that an object placed at 120 on the scale will give a clearly defined and *inverted image* on the retina. Illuminating the eye by means of the ophthalmoscope and placing our own eye at a convenient distance, we shall see conversely an object of the *fundus oculi* producing a clearly defined inverted image at 120 mm. in front of the nodal point of the eye. This image can be received on a slip of ground glass placed at 120 mm.

If the object has a diameter of 1 mm., the reversed image will have a diameter of 6.5 mm., as we have already seen that an object placed at 120 mm. produces with the aid of a + 10 D lens a retinal image $6\frac{1}{2}$ times smaller than itself.

The following experiment is a very striking method of demonstrating the same facts. A figure 13 mm. in diameter cut out of black paper is fastened on the ground glass of the screen and illuminated by a lamp placed behind it. This is formed very clearly on the retina, and measures 2 mm. Keeping the position of everything unaltered except the lamp, which is to be placed behind the eye, the converse is demonstrated, and we see the retinal object projected as an inverted image on to the screen. In performing this experiment, it is advisable to illuminate only the artificial retina. This is easily managed by fixing the lens behind the eye in an orifice pierced in a large opaque screen.

In the same manner that an emmetrope can see at the same distance with the addition of different convex glasses or at different distances by means of the same glass according to the position at which it is placed, so can the inverted retinal image of the emmetropic eye be produced at the same distance by means of different convex glasses or at different distances by means of the same convex glass. But we can easily demonstrate in the emmetropic eye—

1. That the inverted image is always formed at the focus of the convex lens, as that adapts the eye for an object situate at its focus.

2. That for a given lens the inverted image is always of the same size, whatever may be the distance which intervenes between the lens and the emmetropic eye.

3. That the inverted image is larger in proportion as the lens is weaker, and conversely that the retinal images produced by a weak lens are smaller than those produced by a strong lens.

Put the meniscus on the eye and we find the inverted image is produced without any intervening lens at 120 mm. from the nodal point, exactly the same as in rendering the eye myopic 10 D (by lengthening its axis). This is the inverted image which we see by the aid of an ophthalmoscopic mirror (without ob-

jective) in an emmetropic eye exercising its accommodation, or in a myopic eye. We ascertain by the same observation that the inverted image of the emmetropic eye exercising its accommodation, or of an eye myopic by curvature, is larger than that of an eye myopic axially.

To see the *erect image in ametropia* it is evident that the examiner must be furnished with the same glass that would enable the ametropic eye to see clearly at a distance. The correcting lens deflects parallel rays to the amount of convergence or divergence that enables them to be focussed on the fundus of the ametropic eye. Then conversely the luminous rays proceeding from the fundus of an ametropic eye are rendered parallel by the correcting lens, and can therefore be reunited by the emmetropic eye of the observer.

We have seen that for the same degree of ametropia there are several correcting lenses according to the distance at which they are placed. The observer will see the erect image of the ametropic eye with the aid of any of these glasses, only of different dimensions. The influence of correcting lenses naturally affects the dimensions of the ophthalmoscopic images of objects on the *fundus oculi* in the same manner as it does the dimensions of external objects—only the effect is inverse for the images and for the external objects. Thus, in axial myopia the correcting lens placed in apposition with the cornea will reduce the dimensions of the erect ophthalmoscopic image more than the same glass placed at a certain distance. Conversely in axial hypermetropia the erect image will be larger in proportion as the correcting lens approaches the eye and the higher the degree of the hypermetropia.

The erect image will be of the same size in myopia, hypermetropia, or emmetropia, if we place the correcting lens of the axial ametropia in the anterior focus, at 15 mm. from the cornea, or when we apply the correcting glass immediately to the cornea in myopia or hypermetropia by curvature.

In short, if there were on the retina an object of equal size in all eyes, we could experimentally resolve the question of the influence of correcting glasses upon the acuteness of vision, simply by the aid of the size of the ophthalmoscopic images,

without calculation. And this point settled, we could determine, also by the aid of the ophthalmoscope, the kind of ametropia, according to the dimensions of the images of the *fundus oculi.*

It is scarcely necessary to say a word about the inverted image produced by the convex lens in ametropia. It is obvious that the image must always be smaller and closer to the eye in myopia than the inverted image produced without the intervention of a convex lens. Also a myope sees objects nearer and larger through a convex lens than with the naked eye.

As to the inverted image in hypermetropia, we commence with the fact that it is not produced ordinarily, but only by means of a convex lens or by accommodative effort. Moreover, other things being equal, the inverted image will always be farther from the lens and larger in hypermetropia than in emmetropia or myopia. In short, the same convex lens accommodates the hypermetrope for a point not so close to the eye as it does the emmetrope or the myope.

Our artificial eye will enable us to verify our simple formula for the calculation of the size x of the inverted image:[1]

$$x = \frac{\phi}{g''}$$

where $\phi =$ focal length of the convex lens producing the image, the principal focus must coincide with the nodal point of the eye; $g'' =$ the distance from the nodal point to the retina.

This distance, of 15 mm. in the emmetropic eye, is in the axial hypermetropic eye lessened by the number of millimetres (η) we have shortened the eye; on the contrary, in axial myopia, it is proportionately increased. Thus, take a hypermetropia produced by shortening the eye 3 mm., g'' will be $= 15 - 3 =$ 12 mm.

Now, produce the inverted image by means of a convex lens of 17D (59 mm. focal length); ϕ is then $= 59$. Place the lens at 59 on the scale. As this is graduated from the nodal point, the lens is always to be placed in these experiments at the number which corresponds to its focal length in millimetres.

[1] Landolt, Le Grossissement des Images Ophthalmoscopiques, pp. 56, 59, 65. Paris, 1874.

The inverted image x will be in the above example $\frac{59}{12} = 5$, that is to say, five times the size of the retinal object to which it corresponds.

It is evident that we could add paintings of the normal *fundus oculi* and of pathological appearances to this artificial eye for the use of beginners. But we prefer to regard our artificial eye as an instrument for serious investigation in physiological optics. By this limitation its practical utility is not lessened, for we are convinced that although students may learn the management of the ophthalmoscope by an artificial eye, the diagnosis of the affections of the *fundus oculi* should not be attempted except by means of living clinical examples.

Experiments by means of our artificial eye can be indefinitely varied. Thus, by filling it with another fluid in place of water,[1] we can study the influence of the index of refraction of the optic media on the refraction of the eye, &c.

In conclusion, we may add a few words on the exactitude of the experimental results. It is obvious that no optical instrument can furnish results which agree mathematically with the results of calculations. The reasons are well known. We have only to take care that the inevitable errors do not exceed certain limits. The exactitude of our model depends partly upon the cornea and partly on the index of the refraction of the water which is used to fill the globe.

After numerous trials we have succeeded in obtaining a cornea of very satisfactory exactitude. The index of refraction of the water is true when the focus of the eye is exactly 20 mm. behind the anterior surface of the cornea.

We must recollect that the experiments are carried on with the aid of spectacle lenses, and their exactitude is not always free from suspicion. If experiments with a model, in which the above conditions have been carefully observed, do not agree exactly with the calculations, it is most probably due to some fault in the spectacle lenses.

[1] Alcohol is to be avoided, as it dissolves the wax which lutes the cornea.

INSTRUCTIONS FOR THE MANAGEMENT OF THE ARTIFICIAL EYE.

To fill the eye, remove the eye-piece; unscrew the eye, and place the two pieces in a cup of pure water, and shake them occasionally to dislodge any air bubbles attached to the sides. When quite free, screw the two pieces together in the water, and do not take them out till well screwed home. Wipe dry, and screw on to the stem.

The water should be renewed once a week, as it becomes turbid and forms deposits on the cornea and retina. When changing the water it is well to clean the glasses by means of a small stick of soft wood. When the eye is seldom used it is advisable to keep it empty, well dried, and cleaned in its box. To prevent leakage, renew from time to time the grease on the screw; do not use oil, but some mutton suet or other fat having a tolerably firm consistency; do not put any on the inside screw.

The small scale at the back is divided midway by a line marked 0, placed at 20 mm. from the anterior surface of the cornea; the ground glass representing the retina is on the same plane as the external surface of the black disc, so that when the edge of this surface corresponds with the point 0, the eye is arranged for parallel rays.

To observe and measure the image, we fasten by means of a groove on the black disc a cylinder having a micrometer at one end. The micrometer is graduated in half millimetres and requires to be placed in contact with the glass retina, then the lens can be placed in the sliding cylinder at whatever distance the observer needs for clear vision.

To apply the meniscus, clean the surface of the cornea and place on it a small drop of water. Place the meniscus on at a table, concavity upwards, and apply the moistened cornea with a gentle pressure to remove any excess of fluid; gently clean the surface of the meniscus, which should adhere perfectly and carefully; adjust it to the centre.

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